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R. Rivera Tinoco, C. Mansilla, C. Bouallou

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Impact of the Heat Source Selection on the High Temperature Electrolysis Performances and Economic Competitiveness

Rodrigo Rivera Tinoco, CEA, DEN, I-tésé and CEP, MINES ParisTech, France
Christine Mansilla, CEA, DEN, I-tésé, France
Chakib Bouallou, CEP, MINES ParisTech, France

1 Introduction

Among the different processes under development throughout the world, high temperature electrolysis (HTE) seems to be a promising one to carry out massive hydrogen production in the medium to long term. Contrary to the well known alkaline process, hydrogen is to be produced from water steam inside high temperature electrolysis cells, which requires less electric energy than the electrochemical reaction in liquid phase. A relevant advantage of HTE is then the enhancement of process efficiency by direct use of heat for steam generation. In this work we will not detail the diverse operating modes of electrolysis cells, but we will study the possible heat sources that could supply high temperature electrolysis with the needed thermal energy input to evaporate the water stream. After having sorted out the heat sources that would be relevant in a massive hydrogen production context, their impact is assessed, taking into account the following characteristics: available temperature and pressure, and thermal energy cost.

2 Selection of the Heat Source

We first examine the possible heat sources that could provide enough heat to massively produce hydrogen. Up to now nuclear reactors (high temperature and sodium fast ones) and geothermal energy had been considered [1]-[[3]. This study aims at widening this scope through a screening according to four criteria:

- The greenhouse gas mitigation as a priority in a sustainable development context,
- The resource availability so that the process can be operated continuously,
- The heat source capacity to enable large hydrogen production,
- The maturity to allow production in the medium term.

Several potential heat sources did not pass the screening: slurry incineration from wastewater treatment plant demonstrated a low potential and cement kiln smoke was found to be too scattered. Finally four heat sources were selected. They can be divided into two categories:

- The ones involving incineration units: combustion of biomass or domestic wastes [4]-[6],
- The development of techniques to produce steam by using the European Pressurized nuclear Reactor (EPR) and Sodium Fast nuclear Reactor (SFR) [5]-[6].

In the incineration units, the steam needed to reach a defined rate of hydrogen is generated inside the combustion chamber. We assumed that the required vaporization and overheating energy is totally supplied by the fuel considered (biomass or domestic waste). The incineration costs were estimated as a function of the fuel flow in the furnace, its Low Heating Value, and the related incineration operation costs. From these results, the water steam production cost was assessed as a function of the incineration unit size [4]-[6].

As regards the EPR, steam is generated in the secondary loop that usually feeds the turbines with saturated steam in order to generate electricity. Coupling of EPR with HTE assumes drawing off part of the steam which is generated in this loop and introducing it directly into the heat exchanger network to feed the process [5]-[6].

The steam production through a SFR also appeals to drawing off the steam from the tertiary steam loop. Three steam generation techniques have been suggested [6]. Due to safety issues, it is strongly recommended not to generate additional steam by adding more exchangers on the sodium loops. For these last two cases, the thermal energy cost was estimated by assuming a 40 €/MWh electricity cost and by assessing the impact of the steam drawing-off on the heat-to-electricity conversion efficiency.

The heat cost together with the thermal source characteristics are gathered in the following table:

Heat source	**Steam temperature (K)**	**Steam pressure (MPa)**	**Thermal energy cost (€/MWh)**
Biomass	623	2.0	16.5
Domestic waste	713	4.0	21.5
EPR (1)	523	4.0	12.8
EPR (2)	503	3.0	12.8
SFR	484	2.0	15.6

3 Impact of the Heat Source Characteristics

The coupling between the heat source and the HTE process is performed in each case and optimised in order to estimate the lowest hydrogen production cost. The latter is estimated through a simplified levelized production cost model that enables identifying major trends. The optimisation is carried out by means of a FORTRAN program of a modified version of the “Adaptive Random Search Method” [7].

The results are presented in the following figure, by classifying the heat source according to the hydrogen production cost. One should not focus on the figures – which very much depend on the implemented model and related assumptions – but on the general trends.

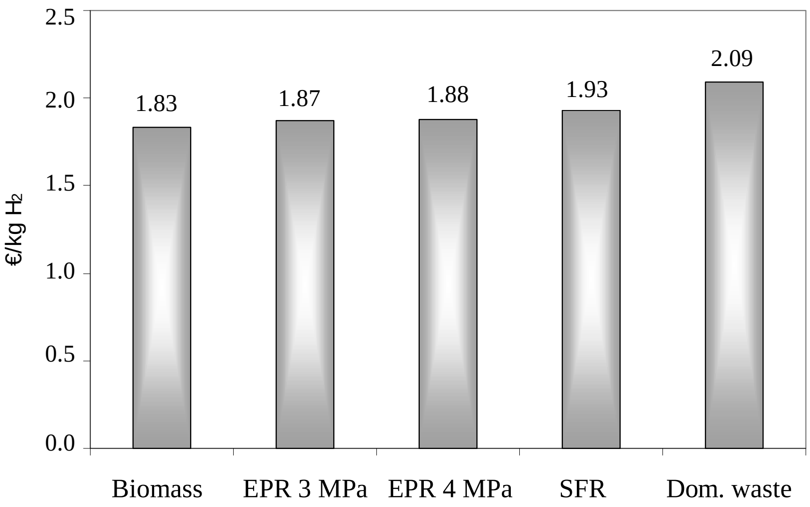

Figure 1: Hydrogen production cost for the selected heat sources, classified by increasing hydrogen production cost.

It first can be noticed that the influence of the heat source on the final production cost is not high. Then let us underline that the heat source that is characterized by the highest available temperature (i.e. domestic waste incineration) also corresponds to the highest hydrogen production cost. This is explained by the fact that besides being characterized by the highest temperature, incineration of domestic waste is also the most expensive thermal energy source (cf. Figure 2).

When comparing the SFR and biomass couplings it can be observed that higher temperatures can lead to diminish the production cost if it does not imply more expensive heat: biomass heat is around 140K hotter than SFR's for a slight overcost and the hydrogen production cost is lower for the biomass coupling. Achieving low hydrogen production costs implies a compromise between low cost thermal energy source and high temperature steam.

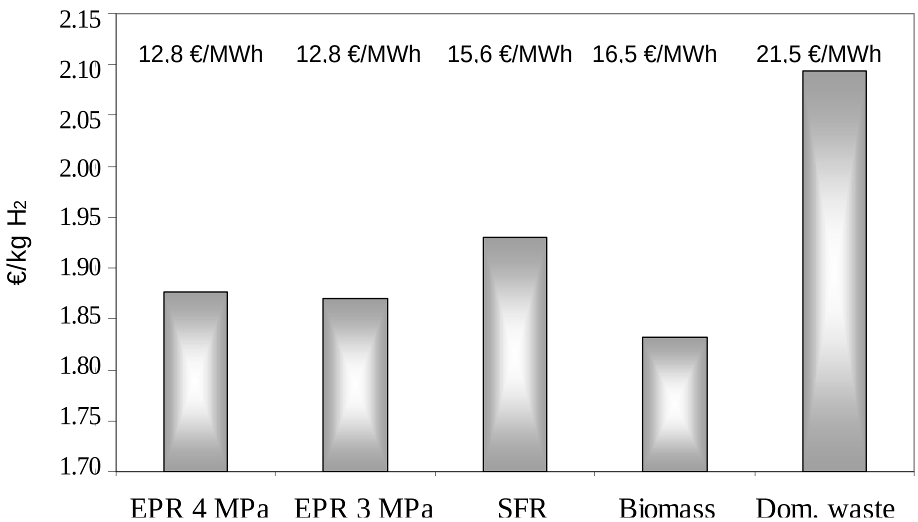

Figure 2: Hydrogen production cost for the selected heat sources, classified according to the thermal energy cost.

Finally, by comparing the two EPR couplings, it can be seen that the heat source pressure does not have a major influence on the hydrogen production cost, within the studied interval.

4 Conclusion

Through the use of a simplified economic model, the impact of the temperature, pressure and thermal energy cost of the heat source on the process competitiveness was assessed. Results show that medium temperature thermal energy sources could be coupled to the High Temperature Electrolysis process without involving strong overcosts. An overall deviation of ±8% was found on the results for the sources here presented, according to the implemented model. Therefore massive hydrogen production through High Temperature Electrolysis could be envisaged considering the use of a wide scope of thermal energy sources.

The thermal energy source needs to demonstrate a compromise between low heat costs and high temperatures: high heat source temperatures favour lower hydrogen costs, but only if the corresponding heat cost is not sharply increased. However, it is not a heavy constraint since the influence of the heat source on the hydrogen production cost is limited.

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